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Evaluation of the multiobjective ant colony algorithm performances on biobjective quadratic assignment problems

Celal Özkale *, Alpaslan Fığlalı

Industrial Engineering Department, Kocaeli University, 41380 Kocaeli, Turkey

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ABSTRACT

The difficulty of resolving the multiobjective combinatorial optimization problems with traditional methods has directed researchers to investigate new approaches which perform better. In recent years some algorithms based on ant colony optimization (ACO) metaheuristic have been suggested to solve these multiobjective problems. In this study these algorithms have been reported and programmed both to solve the biobjective quadratic assignment problem (BiQAP) instances and to evaluate the performances of these algorithms. The robust parameter sets for each 12 multiobjective ant colony optimization (MOACO) algorithms have been calculated and BiQAP instances in the literature have been solved within these parameter sets. The performances of the algorithms have been evaluated by comparing the Pareto fronts obtained from these algorithms. In the evaluation step, a multi significance test is used in a non hierarchical structure, and a performance metric (*P* metric) essential for this test is introduced. Through this study, decision makers will be able to put in the biobjective algorithms in an order according to the priority values calculated from the algorithms' Pareto fronts. Moreover, this is the first time that MOACO algorithms have been compared by solving BiQAPs.

1. Introduction

The quadratic assignment problem (QAP) is one of the NP-hard problems. Since its first formulation introduced by Koopmans and Beckmann [1], it has been used to model a wide variety of areas in real-life problems such as facility layouts, parallel and distributed computing, and combinatorial data analysis. In addition, the traveling salesman problem which is a combinatorial optimization problem, the problems such as maximum clique and graph partitioning problems can be formulized as a QAP. It is possible to see many different formulations to describe QAP instances as structural. Some of these are integer programming, combinatorics, linear algebra, graph theory etc. In spite of some difficulties in solving QAP, with the evolution of new mathematical-based solution techniques that are less than metaheuristic techniques quantifically, it has become more encouraging and challenging.

Multiobjective optimization problems that have to be optimized simultaneously, making it particularly difficult to solve the problem therefore, are characterized by a few objectives. The use of metaheuristics for these problems has been subject to a growing interest in the last decade. The existence of many multiobjective problems in the real world, their intrinsic complexity, and the advantages of metaheuristic procedures to deal with them has strongly developed in this research area in the last few years [2].

* Corresponding author.
E-mail addresses: cozkale@kocaeli.edu.tr, celalozkale@gmail.com (C. Özkale).

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The difficulties of solving multiobjective combinatorial optimization problems have led researchers to investigate the alternatives and approaches that have been getting better performances. In recent years some algorithms based on ant colony optimization (ACO) have been proposed to solve the multiobjective problems. ACO is a metaheuristic inspired by some varieties of ant species that are searching for the shortest path for food resources. Since Dorigo et al. [3] launched a study on the first ACO algorithm (Ant System), many researchers have evaluated different ACO algorithms to solve similar combinatorial optimization problems such as traveling salesman problem, quadratic assignment problems, scheduling, vehicle routing, financing.

Recently, some researchers have designed ACO algorithms to solve multiobjective problems. Many various multiobjective problems included scheduling, portfolio selection, vehicle routing etc. have been solved by the algorithms which are called multiobjective ant colony optimization (MOACO) algorithms and good results have been obtained. It was the starting point of this study that MOACO algorithms have never been used to solve multiobjective QAP (MOQAP) instances. Thus, cited MOACO algorithms in the existing literature have been researched and programmed to solve biobjective quadratic assignment problem (BiQAP) instances. Then, the performances of these algorithms have been evaluated by a multi significance test. A metric called P is introduced in this study for effectively evaluating the biobjective algorithms in a pairwise comparison base.

The paper is organized as follows: Section 2 presents QAP studies, formulations of BiQAP and MOQAP; Section 3 describes ant colony optimization and MOACO algorithms; Section 4 presents computational experiments and results; Section 5 closes with conclusions.

2. Quadratic assignment problem

In the introduction we expressed that QAP has been mentioned in numerous scientific studies. Steinberg [4] used the QAP to minimize the total amount of connections between components in a backboard wiring. Saremi et al. [5] used the QAP and ACO algorithm in improving website structure and usability. Dickey and Hopkins [6] applied it to the assignment of the buildings in a university campus. Hicks [7] developed a genetic algorithm solving QAP for minimizing material movement in a manufacturing cell. Francis and White [8] developed a decision framework for assigning a new facility in order to serve a given set of clients. Laporte and Mercure [9] applied it for balancing hydraulic turbine runners. Geoffrion and Graves [10] used it in the scheduling problem. Elshafei [11] applied it to the facility layout of a hospital. We could see other applications with QAP in statistical analysis [12], archeology [13] and numerical analysis [14]. Benjaafar [15] proposed a formulation of the facility layout design problem to minimize work-in-process. Dell'Amico et al. [16] studied the problem of designing new keyboard layouts able to improve the typing speed of an average message. Duman and Or [17] applied it on the placement problem of electronic components. Ramkumar et al. [18] proposed a new iterated fast local search heuristic for solving QAP. Pillai et al. [19] introduced a QAP design for robust facility layout under the dynamic demand environment. A detailed study on the QAP can be seen in Loiola et al. [20].

We see firstly [1] the QAP as a Boolean program followed by an integer linear programming problem. Since then, this formulation has been used in many studies. f_{ij} is the flow between facilities i and j, d_{kp} is the distance between locations k and p. It is the basic model of QAP:

$$\min \quad \sum_{i,j=1}^{n}\sum_{k,p=1}^{n} f_{ij} d_{kp} x_{ik} x_{jp}, \tag{1}$$

$$\text{s.t.} \quad \sum_{i=1}^{n} x_{ij} = 1 \quad 1 \leqslant j \leqslant n, \tag{2}$$

$$\sum_{j=1}^{n} x_{ij} = 1, \quad 1 \leqslant i \leqslant n, \tag{3}$$

$$x_{ij} \in \{0,1\} \quad 1 \leqslant i,\ j \leqslant n. \tag{4}$$

It is possible to see this model and many similar QAP formulations in the literature. Some of these formulations can be classified as integer programming, graph and group theory, discrete and combinatorial mathematics, trace. It seems that the variety of QAP mathematical structures is promising for the evaluation of mathematical solution techniques.

A wide variety of algorithms has been exposed in an attempt to produce optimum or near optimum solutions for QAP. When the optimum is unknown, or even if it is possible to use the exact algorithms in these instances, to research the local optima in internet-available literature instances is an accepted tendency for the comparison of these algorithms' performances. It is possible to access to like these many performances through the internet and publications for QAP also (see, e.g. [21]). Recently it is possible to see numerous examples with proven optimal solutions. In one of these examples, Zhang evaluated an efficient pivoting based algorithm for QAP. Zhang tried this algorithm onto the instances of Nug, Tai, Chr, Had, Rou, Bur, Esc and Tho n = 12–40. He succeeded in finding the optimum solutions in several seconds to several minutes, and presented about 80 optimal solutions that have never been published in the literature [22]. Besides competing to find opti-

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